BROOKHAVEN NATIONAL LABORATORY

# User Proposal and Request for Beam Time for the NASA Space Radiation Laboratory (NSRL) or Tandem Van de Graaff Radiobiology Laboratory

**Proposal No:** 

**Date:** 11/12/2014

**1. Proposal Type:**

- ☐ Animals
- ☐ Cells/Tissues (human or animal)
- ☒ Physics
- ☐ Other

- ☐ New Proposal
- ☐ Renewal
- ☐ Replacement Proposal — replaces proposal no.: 
- ☐ "Piggyback" Proposal (limited to one run only)

**2. Title of Experiment:** Thick Target Measurements

Funding Source: NASA Space Technology Mission Directorate (STMD) Game Changing Development Program (GCDP)

Grant Title & Number: Advanced Radiation Protection (ARP) Project Thick GCR Shielding Element (project plan: GCDP-02-PLN-14067)

Grant Start Date: 10/1/14 Grant End Date: 9/30/18

*Dates must cover runs being requested

**3. Principal Investigator:** Lawrence Heilbronn

Department: Nuclear Engineering

Institution: University of Tennessee

Mailing Address:
214 Pasqua Engineering Building
1004 Estabrook Road
Knoxville, TN 37996

Telephone: 865-974-0982 Fax: 865-974-0668 Email Address: lheilbro@utk.edu

**4. BNL Account No.:** Pending
(see guidelines, page 3)

**5. Beam Time Request Summary**

Requested Facility and Run: NSRL, Spring 2015

Requested Ions/Energies and Times: Protons 400 MeV (50 hours) and 2.5 GeV (50 hours)
*(please use Beam Time Calculation Table in enclosed Excel spreadsheet)*

**6. Signature**

As Principal Investigator/Spokesperson for this proposal, I certify that everything in this proposal is accurate to the best of my knowledge and that my research team will abide by the rules and regulations of Brookhaven National Laboratory. I also certify that the work described in this proposal is not proprietary and upon completion will be published in the open literature.

**PI/Spokesperson Signature:** Lawrence Heilbronn **Date:** 11/12/2014

*Please sign and submit this front page (hard copy) to Ms. Leah Selva, NSRL Administrator, Brookhaven National Laboratory, 50 Bell Avenue, Biology Dept., Bldg. 463, Upton, NY 11973-5000. In addition, please submit the entire completed application electronically to nsrladmin@bnl.gov.*

**7. Detailed Beam Time Request:** ***Please use Att. 6 Beam Time Calculation Table for beam requests. Requests for sequential beam must be completed on a separate beam time calculation table, see Notes section of Att. 6 for details.***

**A. List equipment and materials to be provided by the beamline (items furnished by BNL):**

Beam-counting scintillator and visual scaler.
Cerenkov detectors.
Mounting hardware for charged particle telescopes.
Fast plastic scintillators
Targets.

**B. List equipment and materials to be provided by the user group (items you will bring to BNL):**

Neutron detectors.
Charged particle telescopes.
Data acquisition and signal processing electronics

**C. Indicate requirements for any special equipment or additional BNL facilities:**

**8. Personnel:** Provide names, citizenships, and contact information for <u>all</u> personnel who will participate in experiments at BNL (use additional sheets if necessary).

| Role | Name | Citizenship | Address | Telephone | Email |
|---|---|---|---|---|---|
| PI | Lawrence Heilbronn | US | 1004 Estabrook Road Knoxville, TN 37996 | 865-974-0982 | lheilbro@utk.edu |
| Coworker | Cary Zeitlin | US | 430 Adams St., Oakland, CA 94610 | 510-325-3836 | zeitlin@boulder.swri.edu |
| Coworker | Ryan Rios | US | JSC, 1 NASA Road, Houston, TX | 281-435-7405 | ryan.r.rios@nasa.gov |
| Coworker | Eric Lukosi | US | 1004 Estabrook Road Knoxville, TN 37996 | 865-974-6568 | elukosi@utk.edu |
| Coworker | Lawrence Pinsky | US | Dep't of Physics, U. of Houston, Houston, TX | 713 743-3552 | pinsky@uh.edu |
| Coworker | Ashwin Srikrishna | US | 1004 Estabrook Road Knoxville, TN 37996 | 865-974-2525 | asrikris@utk.edu |
| Coworker | Luis Castellanos | US | 1004 Estabrook Road Knoxville, TN 37996 | 865-974-2525 | lcastell@utk.edu |
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## 9. Required Approvals

### A. Research Involving Animal Subjects:

Will you use animal subjects in your experiments? ☒ No ☐ Yes Species:

No. of subjects for each run:

Home Institution IACUC approval status:
If approved, provide IACUC protocol no. and approval date; if not approved, provide IACUC protocol submission date.

☐ Not Approved Submission Date:

☐ Approved Protocol No. Approval Date:

BNL IACUC approval status:
If approved, provide IACUC protocol no. and approval date; if not approved, provide IACUC protocol submission date.

☐ Not Approved Submission Date:

☐ Approved Protocol No. Approval Date:

### B. Research Involving Cells or Tissues (human or animal-derived):

Will you use cells or tissues in your experiments? ☒ No ☐ Yes

Cell line/strain or Tissue ID:

Do you have current mycoplasma-free certification from a certified testing laboratory? ☐ No ☐ Yes
Email Ms. Paula Bennett at bennett@bnl.gov at least one (1) month prior to your experiment.

**Does use of these cells/tissues require IRB approval (note: commercially-available cells/tissues are exempt)? ☐ No ☐ Yes**
If you marked **Yes**, complete the following items below:

Home Institution IRB Approval Status:
If approved, provide IRB Protocol no. and approval date; if not approved, provide IRB protocol submission date.

☐ Not Approved Submission Date:

☐ Approved Protocol No. Approval Date:

BNL IRB Approval Status:
If approved, provide IRB Protocol no. and approval date; if not approved, provide IRB protocol submission date.

☐ Not Approved Submission Date:

☐ Approved Protocol No. Approval Date:

### C. Research Involving Recombinant DNA:

Will you use recombinant DNA in your experiments? ☒ No ☐ Yes

Type of recombinant DNA:

BNL Recombinant DNA Advisory Committee Status:
If approved, provide RAC Protocol no. and approval date; if not approved, provide RAC protocol submission date.

☐ Not Approved Submission Date:

☐ Approved Protocol No. Approval Date:

**D. Research Involving Hazardous or Radioactive Materials or Procedures:**
List all biohazards, chemical hazards (explosive, flammable, toxic, corrosive), and radioactive materials and procedures for using these materials in your experiments (radioactive materials do not include irradiated/activated beam line materials).

Liquid scintillator in neutron detectors is flammable, but contained. Any potential leaks are captured by trays placed under the detectors. No other hazardous materials will be used.

**10. Transportation of Experimental Items/Samples Away from BNL**

Will you take experimental items/samples away from BNL? ☒ No ☐ Yes
*All radioactive/hazardous material shipments must be arranged through the BNL Hazardous Materials Transportation Group, contact Mr. Bob Colichio (colichio@bnl.gov) for further information.*

**A. Identify/describe radioactive items/samples:**

**B. Identify/describe hazardous items/samples:**

**C. Identify/describe biological items/samples and shipment method:**
Include any special handling requirements for TSA/Customs inspections (light sensitive, do not X-ray, etc.).

How will biological samples be transported away from BNL? ☐ Personal/Ground ☐ Personal/Air ☐ Contract Carrier

**11. Research Description:**
Provide the information requested below as a separate Word document or PDF and attach to this form. ANSWER ALL QEUESTIONS.

**A. Experimental Proposal:** Provide sufficient detail to justify your beam time request. Proposal is limited to three (3) pages maximum and must include the following information (if you submit your grant progress report for section 11.A.4, the three page proposal limit applies to the remaining sections):

1. Title of proposal (identify proposal as new, renewal, or replacement)
2. Project summary/overview
3. Background and significance
4. Progress report (for renewal proposals, you may submit your most recent funding agency grant progress report; for new proposals, include any supporting preliminary results). This report should include progress accomplished in prior runs, problems encountered and lessons learned, any deferrals, and responses to previous SACRR proposal review items.
5. List of three (3) publications (to assist the SACRR in its evaluation of previous work/experience and project feasibility).
6. Description of PI and team's previous accelerator experience (1 paragraph maximum).

**B. Beam Time Request:** Provide sufficient detail to justify the amount of beam time you are requesting. SACRR must be convinced that previously awarded beam time was efficiently and judiciously used, and that you will require the full amount of time for your current request. You must also justify the requested ion species. For this section, you must include:

1. Detailed experimental plan for all experiments to be conducted
2. Beam time calculations (see Att. 6 Beam Time Calculation Table. Requests for sequential beam must be completed on a separate beam time calculation table, see Notes section of Att. 6 for details). Include the total time requested for all ions and energies in Beam Time Request Summary (located on page 1).
3. Other information that may be helpful in justifying your beam time request to SACRR (optional).

# Thick Target Measurements (Renewal/Continuation)

**Summary/Overview** Recent calculations conducted at NASA's Langley Research Center (LaRC) indicate that there may be an optimal thickness of shielding material that provides maximum protection from Galactic Cosmic Rays (GCRs) in free space. The metrics used in radiation protection are the dose equivalent (H) and effective dose (E). The calculations determined these quantities, as well as dose (D), in fully enclosed shielded environments in a GCR field. The incident primary GCR field was transported through the shielding material, and because the environment was fully enclosed, the radiation field inside the shielding included both particles from primary GCR transport through the shielding material and particles from backscattering inside the environment. The fully enclosed environment is the key element leading to the conclusions found in the LaRC calculations. If GCR is transported through a single wall with no possibility of back scattering, D, H, and E will decrease with increasing shielding thickness. However, if a second wall is added behind the first wall (the direction defining behind is the direction of the incoming GCR particle), any primary GCR ion that survives the initial transport through the first wall, as well as all secondary radiations that survive transport through the first wall, can undergo additional interactions in the back wall. Backscattered radiation coming from interactions in the back wall adds to D, H, and E in the fully enclosed environment, and it is this mechanism that is believed to produce the effect seen, where H and E decrease with increasing wall thickness up to approximately 40 g/cm$^2$, and then increase as the thickness increased beyond that point.

**Background and Significance** If the calculations conducted at LaRC are correct, the results are critically important for deep-space mission planning. Mission costs are proportional to the amount of mass either being launched or being utilized on lunar or planetary surfaces, and if an optimal shielding thickness exists, this has obvious consequences on mission costs. In addition, an optimal thickness suggests that there is a minimum H and E in a GCR environment from which there is no possibility for further reduction with additional shielding. If H and E do have minima, they can be taken as lower limits for crew exposures over the duration of the mission. Hypothetical lower limits have implications for mission durations, or at the very least, provide information about the expected radiation risk resulting from the mission.

Experimental verification of the LaRC calculations is needed. Measurements of D, H, and E are necessary but not sufficient for model validation. The key factor responsible for the rise in H and E beyond a particular thickness is believed to be the radiation field produced by interactions in the back wall. The critical elements in that field are believed to be the secondary neutrons, pion, and light ions (d, t, $^3$He, $^4$He). As such, verification of the LaRC calculations will require a characterization of the radiation field consisting of particle identification, particle energy, and if possible, particle direction.

The experimental verification proposed here will be a program of accelerator-based experiments in which detectors will be placed between two shielding walls. The accelerator will provide mono-directional, mono-isotopic and mono-energetic beams of GCR-like particles such as protons, He, C, and heavier nuclei with energies ranging from

100 MeV/nucleon to a few GeV/nucleon. Beams will strike the forward shielding wall, and surviving beam particles and secondary particles will then strike the rearward wall. Detectors will be positioned between the walls, providing information on particle types, energies, and points of origin (forward or backward wall). The experiments will provide LaRC investigators with the data needed to test the ability of their transport codes to correctly predict the radiation field inside an enclosed structure in space.

## General Experimental Plan

A conceptual design of the experimental setup is shown below in Figure 1. Beam is incident upon the forward wall, moving from left to right. Any primary beam particles and secondary particles that escape the forward wall continue on to the back wall and undergo interactions there. Those interactions include backscattering and additional nuclear interactions in the wall, both of which can create a stream of particles moving into the gap between the forward and back walls. In between the forward and back walls, detectors will be deployed that will detect charged light ions, neutrons, intermediate mass fragments ($2<Z<14$), pions, gamma rays (if needed), electrons and positrons (if needed).

Detector systems will be placed at various locations, most of which will be between the two shielding walls. The detector types include: NaI (charged light ions, gamma rays, positrons via annihilation signature); liquid and solid scintillators (neutrons, charged ions, beam scintillator, electrons, positrons); Cherenkov (light ions, pions, electrons, pions); Bonner sphere (neutron); and Medipix (Si detector for charged particles, tracking)

## Specific Plan for Fall 2015 Run

100 hours of beam time will be split evenly among 2 beams: protons at 400 and 2.5 GeV. Each beam is planned to have 12 configurations, with each configuration running 2 hours. A configuration is defined as a target material with a specified thickness and a specified detector orientation. Each target+target-thickness combination will have two detector orientations; one orientation will detect secondary particles thrown downstream from the target, and the other orientation will detect particles scattered from the back wall. An additional one hour of each beam time will be required for calibration and adjustments of the signal processing electronics based on the signals generated by the beam striking the target. Two target materials will be used (Al and a hydrogenous material such as polyethylene), and each target will be run at three different thicknesses (30, 40 and 50 g/cm$^2$). The targets will be centered along the direction of the beam. Detectors will be placed in positions both along the beam (on the rails) and off axis. Previous physics experiments have shown that there is adequate space both beam left and beam right in which to stage the detector systems.

Data acquisition will be handled by both CAMAC and VME based systems. The CAMAC system is the UTK data acquisition system, and the VME system is the acquisition system used by staff physicists at the NSRL. Both are mature systems and have been used in many previous experiments.

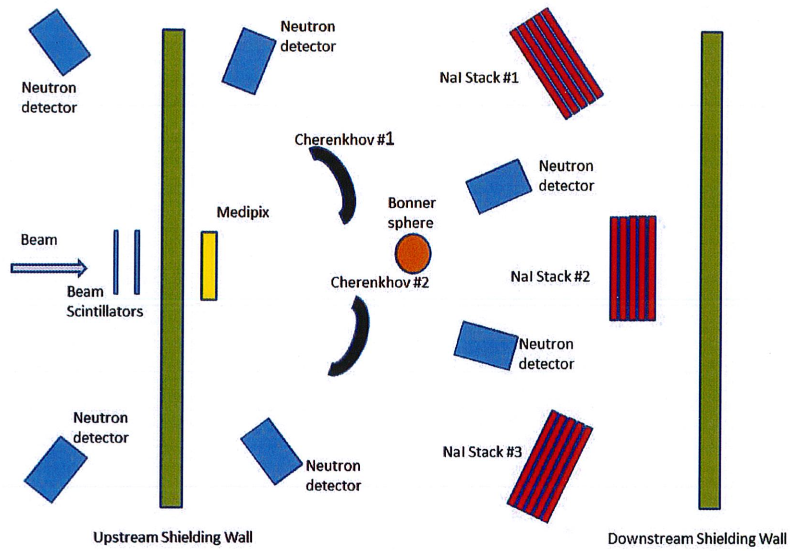


Figure 1. Conceptual design of an accelerator-based measurement testing the model predictions of the radiation environment in a fully enclosed, shielded structure.

No special power requirements are needed, and there are no special handling considerations for the detectors or targets. Beam currents will be extremely low, and as such activation of the target materials and detectors is expected to be minimal and pose no handling problems after irradiations are completed.

**Related Publications:**

1. L. Heilbronn et al., Secondary neutron-production cross sections from heavy-ion interactions in composite targets, Phys. Rev. C73, 024603 (2006).

2. C. Zeitlin et al., Comparisons of fragmentation spectra using 1 GeV/amu $^{56}$Fe data and the PHITS model, Rad. Meas. 43, 1242-1253 (2008).

3. T.C. Slaba, S.R. Blattnig, M.S. Clowdsley, S.A. Walker, F.F. Badavi, An improved neutron transport algorithm for HZETRN, Adv. Space Res. 46, 800-810 (2010).

**Previous Accelerator Experience** The PI, Dr. Heilbronn, has more than 30 years of experience performing accelerator experiments. Dr. Zeitlin, who will lead the analysis of charged particle data, also has 30+ years of experience. Both have performed many experiments previously at NSRL, as has Dr. Rios, whose experience includes work at the LHC at CERN. Dr. Rusek and Dr. Siverts each have 25+ years of experience, and Dr. LaTessa has over 10 years of experience.

**Progress Report:** The first experiment will take place in Spring 2015, so no data has been acquired to this point. Simulations of the experiment using PHITS and MCNP-X continue and are being incorporated into the process of designing the spring and fall 2015 runs